

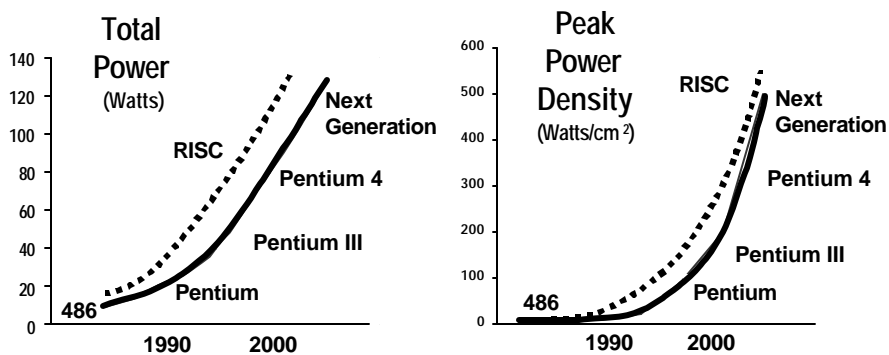


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Active Micro-Channel Cooling

## The Heat Problem

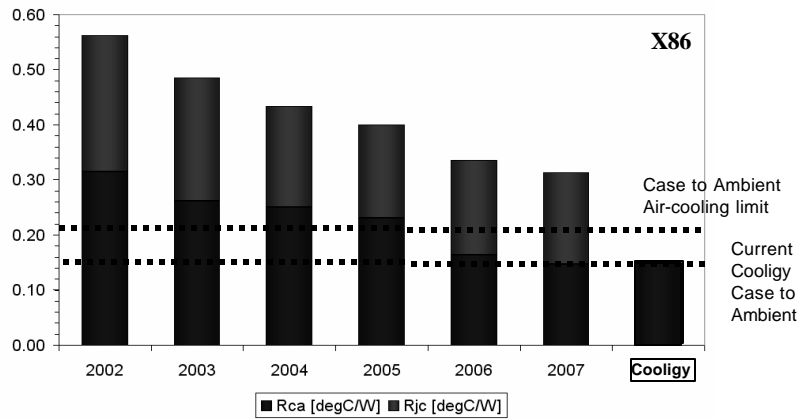


### Why Keep CPUs Cool?

- ◆ Greater Performance
- ◆ Better Reliability

# Microprocessor Thermal Requirements

Desktop Microprocessor Thermal Management Requirement Through 2007



Source:

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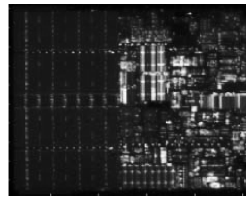
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## Microprocessor Thermal Management

### ♦ Microprocessor thermal management challenges

- ♦ Very high average and peak power densities
  - $Q''_{\text{average}} > 150 \text{ W/cm}^2$
  - $Q''_{\text{peak}} > 500 \text{ W/cm}^2$
- ♦ Thermal management requirement outpaces air-cooling technologies



Genossar, D. and Shamir, N., 2003, "Intel® Pentium® M Processor Power Estimation, Budgeting, Optimization, and Validation", Intel Technology Journal, Vol. 7(2), pp. 44-49

### ♦ Electro-kinetic microchannel cooling system advantages

- ♦ Orders of magnitude higher effective heat transfer coefficient compared with air-cooled heatsinks and liquid-cooled cold-plates
- ♦ Microchannels can be readily implemented for hot-spot cooling
- ♦ Very efficient liquid-air heat exchanger

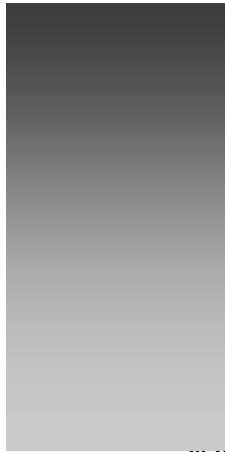
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# Keeping Cool

CPU Power



Natural Convection



Active Fan Sink



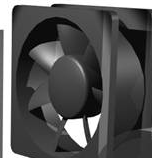
Passive Fluid Heat Pipe

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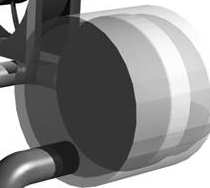
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## Microchannel Cooling System

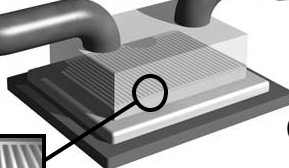
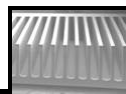
Radiator



Electrokinetic Pump



Microchannel Heat Collector

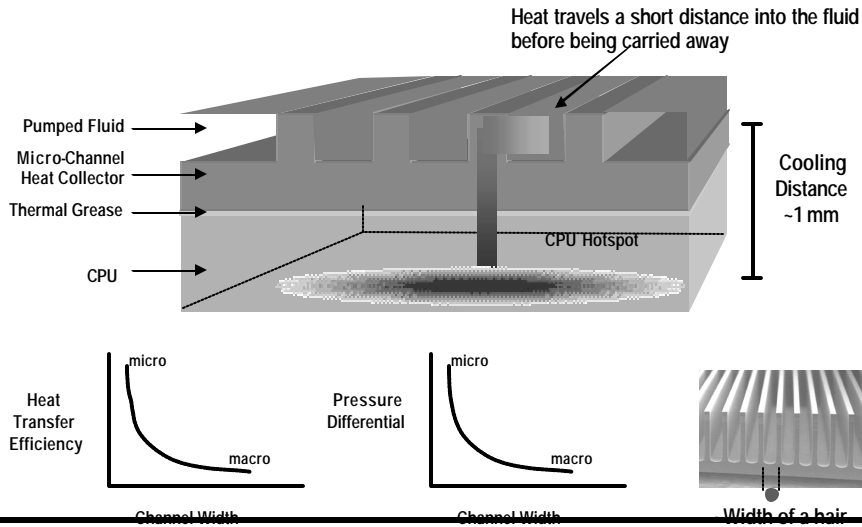


CPU

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## Micro-Channels Provide Highest Performance

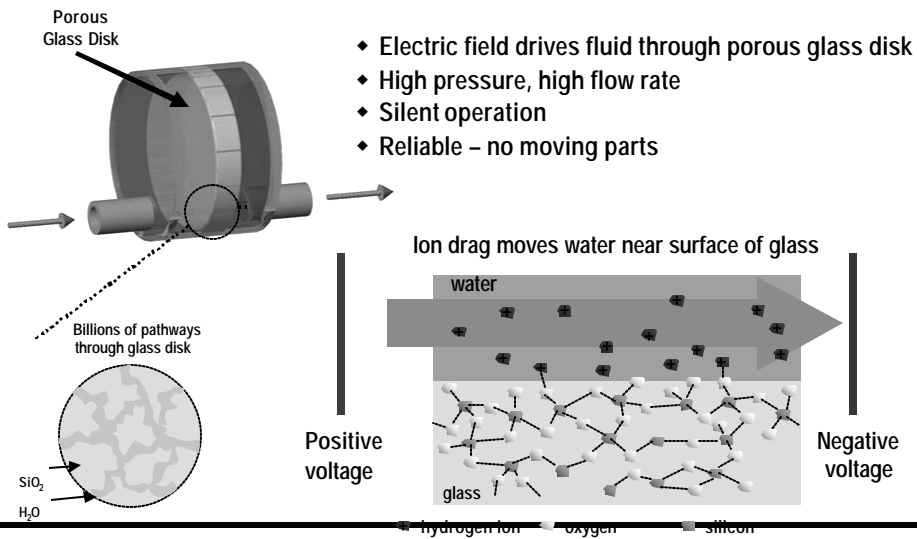


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## Electro-Kinetic Pump – No Moving Parts



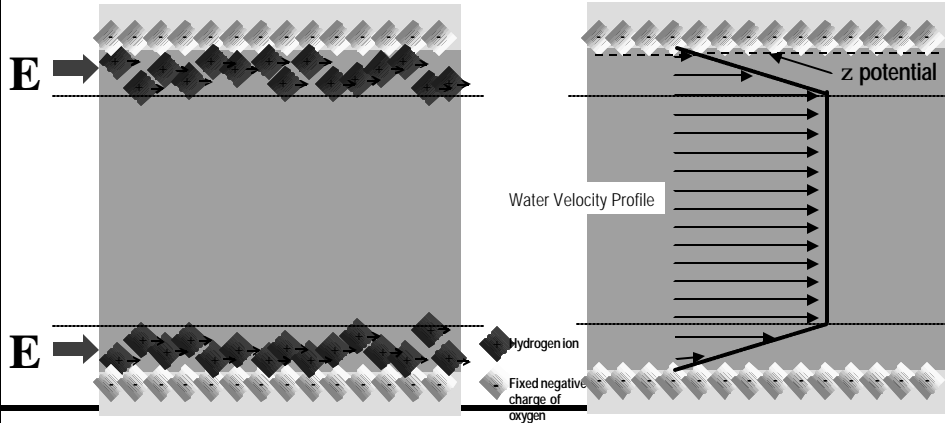
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# Electrokinetic Fluid Flow

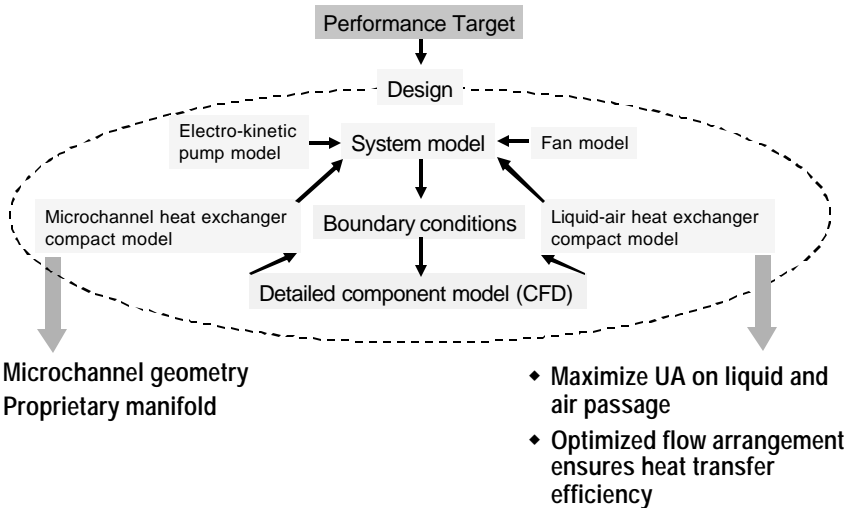
The fixed surface charge creates a diffuse double layer region of net positive charge near the surface. Applied electric field acts on charges and causes fluid to flow.



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# System Thermal Design

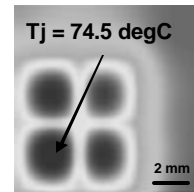
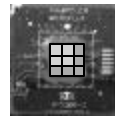
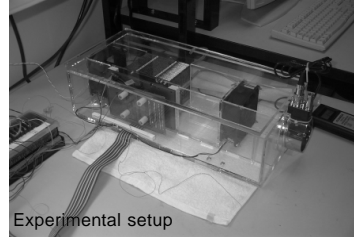


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## Thermal Die Numerical and Experimental Results

	Simulation	Experiment
TDP [W]	150	150
$Q''_{avg}$ [W/cm <sup>2</sup> ]	250	250
$Q''_{peak}$ [W/cm <sup>2</sup> ]	360	360
Ta [degC]	25	25
V_dot_air [CFM]	50	51
V_dot_l [ml/min]	300	~280
Rja [degC/W]	0.38	0.37



Junction temperature distribution  
150W, 360W/cm<sup>2</sup>, 300ml/min @ 25degC water

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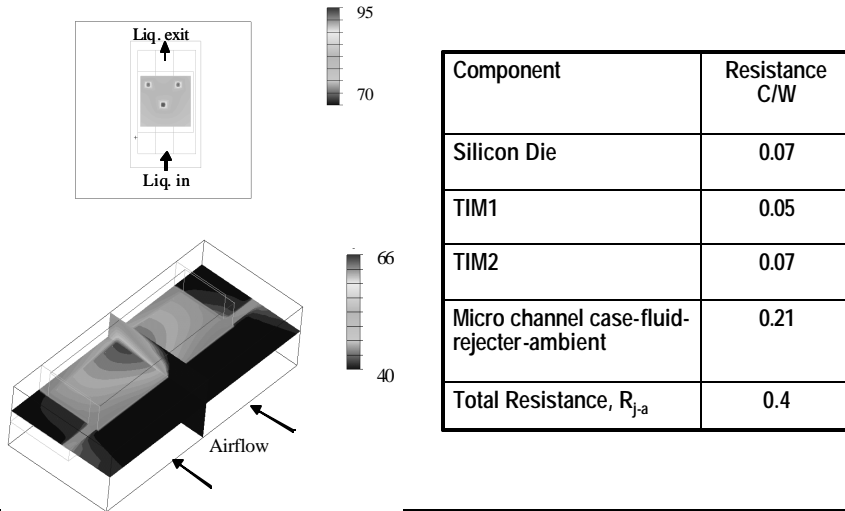
## Pentium 4 Model Parameters

Ambient temperature, C	40
CPU die size, cm <sup>2</sup>	1
<b>CPU power, W</b>	<b>137</b>
Die thickness, mm	0.75
Spreader size, mm	35 x 35
Integrated heat spreader thickness, mm	1.2
Integrated heat spreader material	Cu
Hot spot size, mm <sup>2</sup>	1
<b>Power density at hot spot, W/ cm<sup>2</sup></b>	<b>500</b>
No. of hot spots	3
Rejecter size (mm)	160 x 50 x 40
Airflow through rejecter, cfm	28

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## Simulation Results



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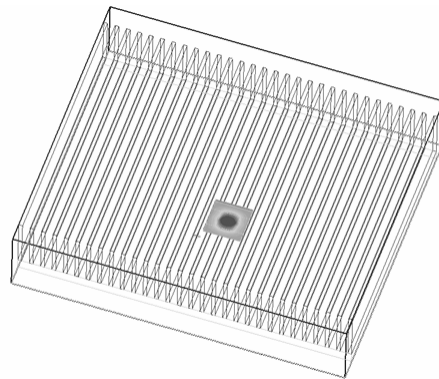
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## Passive Cooling: Fan Heat Sink

- ♦ Average power cooling
- ♦ Heat must spread up to reach cooling air
- ♦ Fan heat sink is many times larger than the CPU



120 Watt CPU  
Hot spot in center



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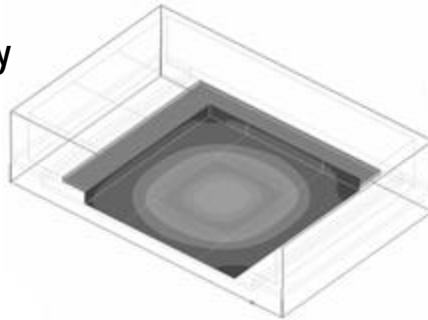
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# Active Micro-Channel Cooling

- ♦ Efficiently cools hot spot
- ♦ Active microchannel cooling area is 7-10 times the area of the die
- ♦ Cooling fluid brought directly to hottest areas on die



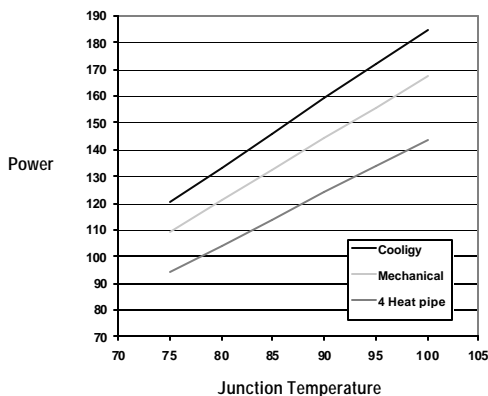
120 Watt CPU  
Hot spot in center



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## Example: RISC Workstation Power Scaling



	Cooligy	Mechanical	4-Heat pipe
Rejecter size	120x90x90	120x90x90	120x90x90
Liquid flow rate ml/m	300	1800	
Airflow per CPU, cfm	43	43	43
Hot spot Flux, W/cm²	500	500	500

### Fluid Cooling

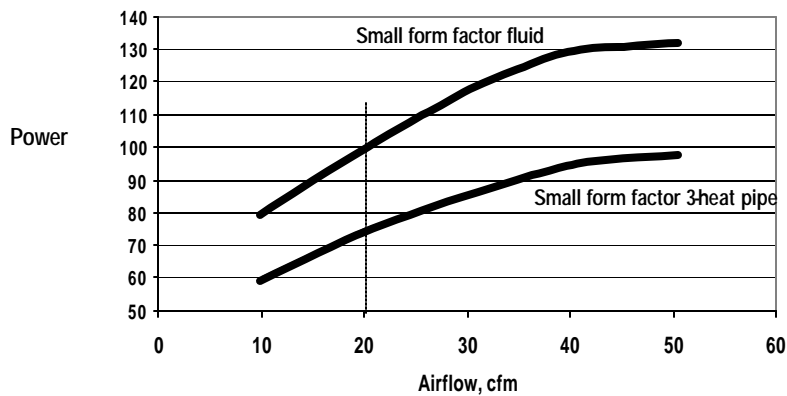
- Higher total power per CPU
- Lower fan speed

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## Active Fluid Air Flow Advantage

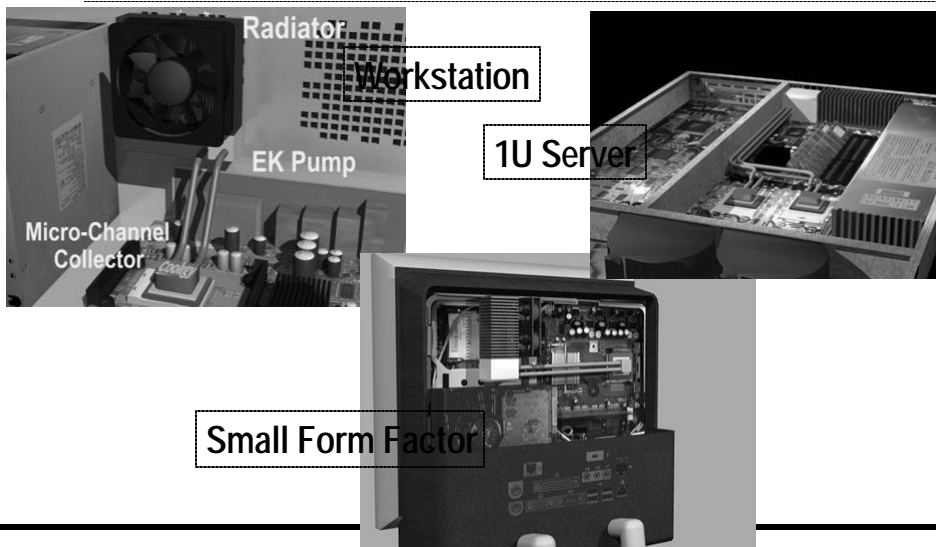


Small form factor radiator  
Ambient temperature = 38C

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## Target Applications



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